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ORIGINAL RESEARCH

KINEMATIC ANALYSIS OF KNEE VALGUS DURING DROP VERTICAL JUMP AND FORWARD STEP-UP IN YOUNG BASKETBALL PLAYERS

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ABSTRACT

Purpose/Background: Lower limb asymmetry between dominant and nondominant limbs is often associated with injuries. However, there is a lack of evidence about frontal plane projection angle (FPPA) of the knee joint (knee valgus) during drop vertical jump (DVJ) and forward step-up tasks (FSUP) in young basketball players. Therefore, the purpose of this study was to assess the FPPA (i.e., dynamic knee valgus) via 2D video analysis during DVJ and FSUP tasks in the dominant and nondominant limbs of young male basketball players.

Methods: Twenty seven young male basketball players (age 14.5 ± 1.3 y, height 161.1 ± 4.1 cm, weight 64.2 ± 10.2 kg) participated in this study. The participants were asked to perform a bilateral DVJ and unilateral FSUP tasks. Kinematic analysis of FPPA was completed via a two-dimensional (2D) examination in order to evaluate the knee valgus alignment during the beginning of the concentric phase of each task. Knee valgus alignment was computed considering the angle between the line formed between the markers at the anterior superior iliac spine and middle of the tibiofemoral joint and the line formed from the markers on the middle of the tibiofemoral joint to the middle of the ankle mortise. Paired t-tests were used to evaluate differences in tasks. Standard error of measurement (SEM) was calculated to establish random error scores.

Results: There was no difference in knee valgus angle during the DVJ task between dominant (20.2 ± 4.4°) and nondominant legs (20 ± 4.1°; $p = 0.067$). However, a significant difference was noted during FSUP between the non-dominant limb (18.7 ± 3.4°) when compared to the dominant (21.7 ± 3.5°; $p = 0.001$) limb.

Conclusion: Two dimensional kinematic analysis of knee FPPA may help coaches and other professionals to detect asymmetries between dominant and nondominant limbs, and to develop training programs with the goal of reducing overall lower extremity injury risk.

Level of evidence: 2b

Keywords: Athlete development; injury prevention; knee; motor behavior; valgus moment

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INTRODUCTION

Basketball is a very popular team sport throughout the world, characterized by short and explosive efforts, agility, rapid changes of direction, as well as jumping and landing movements.[1] Regardless of the specific motor skills, the jumping and landing abilities of these athletes are one of the key elements in successful basketball performance.[2] However, excessive knee valgus or hip adduction during jumping, squatting, and lunging movements are often considered as a mechanism associated with lower extremity injuries. [3-6]

Multiple contributing factors, such as previous injury, limb dominance, or specific sport demands, could result in the development of muscle strength imbalances among athletes.[7] These imbalances not only may affect performance but also could increase incidence of injury.[8] The majority of non-contact anterior cruciate ligament (ACL) injuries are reported in scientific literature as being associated with sports that involve rapid combinations of limb rotation movements, landing, or deceleration prior to change of direction (cutting) during agility tasks, such as basketball.[9-11] Specifically, these injury mechanisms have been connected to excessive dynamic knee valgus (hip internal rotation, knee valgus or tibial rotation angles), contralateral pelvic drop, and a shift in the center of mass away from the stance limb induced by hip abductor weakness.[12]

However, it is unclear whether these imbalances are a result of sport-specific training or of other factors such as injury or difference in leg length.[13] Limb dominance is one of the factors that could impact lower limb strength imbalance, and consequently, affect injury risk.[14] Possible reasons for bilateral strength asymmetries might be inadequate or incomplete rehabilitation program after injury with resultant differences in agonist-antagonist ratio, training methods, and specific motor demands of different sports.[7] Limb dominance could be attributed to repeated use or emphasis on one lower extremity during sport, for example a leg being a drive leg for hitting, jumping, or base running tasks.[8]

Previous authors have examined lower extremity imbalances via frontal plane kinematic analysis of the knee valgus collapse during dynamic tasks.[3-6] Drop vertical jump (DVJ) is one of the tasks often utilized to assess athletic injury risk and performance capacity.[2,15] Herrington[6] used kinematic analysis to investigate knee valgus during DVJ and unilateral step landing tasks in elite female basketball and volleyball players. Basketball athletes in their study showed lower degree of knee valgus during unilateral step landing when compared to volleyball athletes. However, the authors found a greater knee valgus angle for the dominant limb ($24.2 \pm 11°$) when compared to the nondominant limb ($13.8 \pm 8.3°$) for the female basketball athletes during DVJ.

The forward step-up (FSUP) is an important daily activity that has been adopted as a closed-kinetic chain exercise during many rehabilitation programs. The FSUP is also used to assess hip and knee imbalances because it is characterized by hip and knee extension, and hip abduction and adduction in a dynamic, single-leg fashion, which is thought to elicit a high level of gluteus medius activation (i.e., $> 60\%$ of maximal voluntary contraction).[16,17] Lin et al[18] investigated the in vivo articular cartilage contact kinematics at the tibial plateau and femoral condylar surfaces during a FUSP activity in healthy subjects, by measuring the transepicondylar axis and the geometric center axis using a fluoroscopic imaging system. They noted that when the FSUP is performed without imbalances, medial and lateral compartments had similar motion patterns, avoiding the medial-pivoting motion (i.e., lower mobility of medial condyle in translation compared to the lateral side during flexion/extension of the knee). However, Lubahn et al[19] reported that the weakness or poor synchrony of the rectus femoris, hamstrings, and hip abductor/adductor muscles during FSUP exercise caused excessive mediolateral or anteroposterior movement, and consequently a higher level of mechanical loads in tibiofemoral and patellofemoral joints, respectively. These conditions are functional and structural injury mechanisms often associated with traumatic ACL tears.[9,12]

Understanding knee joint kinematics during step-up and jumping activities is important for optimizing rehabilitation protocols in order to enhance efficacy in treatment of common lower extremity injuries in sports, such as ankle sprains and ACL tear.[8,12] However, there is still a lack of evidence about kinematic analysis of frontal plane projection angle (FPPA) of the knee joint during DVJ and FSUP tasks between dominant and nondominant limb of young basketball players. Additionally, previous evidence indicates that individuals who exhibit high FPPA also demonstrate movement patterns that place increased stress on the ACL and patellofemoral joint, increasing risk of injury.[5,20] Therefore, the purpose of this study was to assess the FPPA (i.e., dynamic knee valgus) via 2D video analysis during DVJ and FSUP tasks between dominant and nondominant limbs of young male basketball players. The authors hypothesized that young male basketball players would show greater knee valgus angle for the nondominant compared to the dominant limb during DVJ and FSUP tasks.

METHODS

Subjects

This observational study was designed to compare FPPA of knee joint during jumping and step-up tasks between dominant and nondominant limbs of young male basketball players was conducted at the Center of Kinesiology and Performance (NUCAR). Thirty-two young male basketball players (age 14.5 ± 1.3 y, height 161.1 ± 4.1 cm, weight 64.2 ± 10.2 kg) with background in regular strength or plyometric training volunteered to participate in this study. All participants had at least four years of basketball experience (4.5 ± 1.2 years), averaging four 60-min sessions per week. All participants were active in competitive sports training or were active in competition one to four times per week. The exclusion criteria adopted for the current study was: (a) potential medical problems or a history of ankle, knee, or back pathology that compromised their participation or performance tests proposed; (b) any lower extremity reconstructive surgery in the prior two years. Twenty-seven subjects met the inclusion criteria and were enrolled in this study.

Prior to data collection, the participants and their parents were informed about the experimental procedures and about possible risks and benefits associated with participation in the study and signed an informed consent before any of the tests were performed. The procedures were approved by the Institutional Ethics Review Committee of the Rio de Janeiro Federal University in accordance with the current national and international laws and regulations governing the use of human subjects (Declaration of Helsinki II).

Procedures

To simulate the jumping and lunging tasks that occur during athletic competitions, participants were asked to perform a bilateral DVJ and unilateral FSUP of both dominant and nondominant limb. Each participant was asked to perform three to five practice trials of both tasks.[2] Once participants were familiarized with the tasks, they were asked to perform three test trials for each task; the sequence of unilateral FSUP (left or right leg first) or DVJ task was randomized for each participants.

The DVJ task was performed by having the subject stand on a 40-cm–high bench, the participant was then instructed to drop directly down off the bench on to a mark 40 cm from the bench, landing on both feet, and immediately perform a maximum vertical jump, raising both arms to provide countermovement (Figure 1). The FSUP movement involved the subject stepping up a 40-cm–high bench, and landing with the opposite leg on to a mark 40 cm from the bench (Figure 2). The subject stepped with the posterior border of the initial leg heel landing flush with the leading edge of the step box and with heel-to-toe foot

Figure 1. *Frontal-plane projection angle during drop vertical jump.*

position perpendicular to the leading edge of the box. The starting position was characterized by the trail leg in 10° hyperextension at the hip measured from the greater trochanter to the midline of the femur. The subject then extended the knee and hip of the initial leg until the trail foot was placed on the box lateral to the lead foot. The trail foot then returned to starting position, and the process was repeated. Although the definition of the dominant or preferred jumping leg is very important in the interpretation of test results, this distinction remains controversial in the literature.[14] In the current study, limb dominance was operationally defined as the preferred kicking leg or the foot used for stair climbing. [21]

Kinematic analysis was performed via a two-dimensional (2D) FPPA of knee alignment measured during the DVJ and FSUP tasks. The reliability, measurement error, and validity of this 2D analysis has been previously established in comparison to three dimensional (3D) measures.[5] A digital video camera (Sony CX505VE32 GB HDD model; New York, NY, USA) was placed perpendicular to the subject's knee (i.e., dominant and nondominant), two meters anterior to the participants' landing target,

Figure 2. *Frontal-plane projection angle during forward step-up.*

and aligned perpendicular to the frontal plane. The digital images were imported into a digitizing software program (Quintic 4, Quintic Consultancy Ltd., Cambridge, England, United Kingdom), sampling at 30 Hz. Eight spherical markers were attached to the skin with double-faced adhesive tape at the following locations: the anterior superior iliac spine, the greater trochanter, the lateral femoral condyle, the lateral tibia condyle, middle of the tibiofemoral joint, middle of the ankle mortise, the lateral malleolus, and the fifth metatarsal.[6] The verbal instructions proposed by Khuu, Musalem, Beach[2] were adopted in the current study.

Knee valgus alignment was computed using the angle between the line formed between the markers at the anterior superior iliac spine and middle of the tibiofemoral joint and the line that formed from the markers on the middle of the tibiofemoral joint to the middle of the ankle mortise. The average knee valgus angle value from the three trials was used for analysis and computed for each leg during FSUP and DVJ tasks, respectively.[20] Negative FPPA values reflected excursion of the knee away from the midline of the body, or varus alignment. On the other hand, positive FPPA values reflected dynamic knee valgus, excursion of the knee towards the midline of the body so that the knee marker was medial to the line between the ankle and thigh markers. The within-session reliability of this method has been described.[5] All procedures were performed by the same researcher.

Statistical Analyses

Descriptive statistics (mean and standard deviation [SD]) were computed and presented for each dependent variable. The intraclass correlation coefficient (ICC = (MSb- MSW) / [MSb + (k-1) MSW), where MSb = mean-square between, MSw = mean-square within, and k = average group size, was calculated to determine the reproducibility of intersubject for each measure. To evaluate differences between dominant and nondominant limb in knee valgus paired t-tests were used during both tasks. Standard error of measurement (SEM) was calculated to establish random error scores.[20] The p-value was set at $p \leq 0.05$. All statistical analyses were carried out using SPSS statistical software package version 20.0 (SPSS Inc., Chicago, IL).

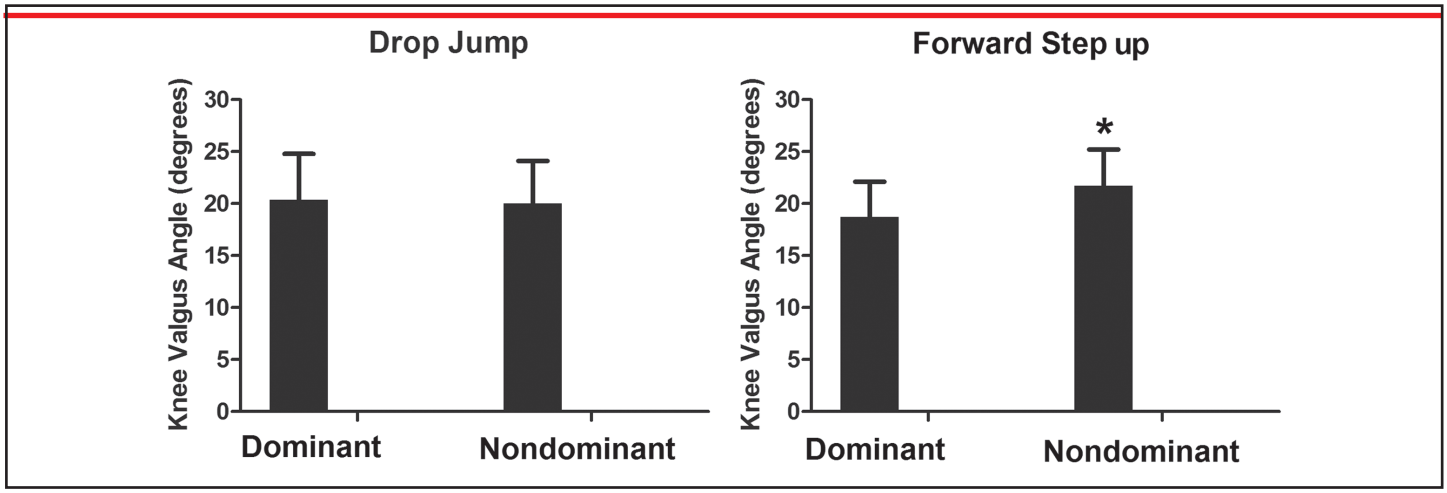

Figure 3.

RESULTS

The ICC's and method errors are presented in Table 1. SEM scores ranged from 2.31° to 3.09° when examining the video analysis of DVJ and FSUP.

During the DVJ task there was no difference in FPPA between dominant (20.2 ± 4.4º) and non-dominant limbs (20 ± 4.1º) in the young basketball players tested (p = 0.067) (Table 2). However, a significant difference in FPPA was noted for nondominant limb (18.7 ± 3.4º) compared to dominant (21.7 ± 3.5º) limb during FSUP task (p = 0.001).

DISCUSSION

The purpose of this study was to assess the FPPA (i.e., dynamic knee alignment) via 2D video analysis during DVJ and FSUP tasks between dominant and nondominant limbs of young basketball players. The author`s hypothesis was that there would be a significant difference in knee valgus angle of nondominant versus dominant limb. The key finding from the current study was that a significantly greater FPPA was noted for the nondominant versus dominant limb (i.e., 16%) during FSUP task. However, there was no difference in FPPA between limbs during DVJ. This imbalance noted between dominant and nondominant limb during FSUP are in accordance in results from previous authors who found asymmetries between dominant and nondominant limbs during unilateral tasks performed by young athletes.[7,21,22]

Excessive knee valgus during dynamic tasks such jumping, running, and cycling has been reported in the scientific literature as a risk factor for sustaining lower extremity injuries in sports.[3,8] Many studies use 3D motion capture methods to assess lower limb kinematics, which is expensive and time consuming to undertake, compared with 2D video analysis.[20] Thus, the use of 2D video analysis has become more

Table 1. *Intraclass correlation coefficient (ICC), confidence interval (CI), and method error (ME) of exercise test measurements for intrasubject reliability (N = 27).*

Exercises	Drop Jump	Forward Step-up
Dominant	20.2 ± 4.4º	18.7 ± 3.4º
Nondominant	20 ± 4.1º	21.7 ± 3.5º*

*Significant difference for dominant limb.

Table 2. *Mean and SD values of knee valgus angle between dominant and nondominant limb during jumping and lunge task.*

Exercises	ICC	95% CI	ME(CVME)
Drop vertical jump	0.92	(0.70, 0.99)	2.0 (2.9)
Forward step-up	0.91	(0.71, 0.91)	2.0 (2.9)

CVME: coefficient of variation of method error (percent variation in measurement between trials) common as a simple, inexpensive, and reliable alternative for researchers, rehabilitation professionals, and coaches to investigate athletes' injury-risk. [5]

Considering DVJ task, the results of the current study demonstrated no difference in FPPA between dominant (20.2 ± 4.4º) and nondominant leg (20 ± 4.1º). These data were similar to those noted by Khuu et al,[2] Doherty et al,[14] and Menzel et al[13] who did not find differences in FPPA of knee joint and asymmetries between limbs during vertical jump tasks. On the other hand, the results of the present study demonstrated a significant difference in knee valgus angle was noted for nondominant limb (18.7 ± 3.4°) versus dominant limb (21.7 ± 3.5°) during FSUP task (16%). Pappas et al[8] and Newton et al[7] both reported that knee valgus angles increases when unilateral step-up or step-down tasks are performed when compared with bilateral jumping tasks.

Step-up exercises are often adopted in rehabilitation programs due to the benefits of including loaded single-leg exercises to improve functional stability,[23] providing the athlete a method to practice or improve dynamic control when supported by a single limb, as would occur during during unilateral landings and cuts, thereby offering the potential to reduce LE injury risk.[16] Previous studies conducted with college athletes suggested that imbalances between dominant and nondominant limbs of 15% or more may increase the rate of lower extremity injury, especially in young athletes,[3,8,24] making the 16% difference seen in the current subjects worth considering as potentially clinically relevant. Additionally, the step-up exercise requires unilateral support, as well as dynamic pelvic and trunk stabilization. The increased anterior tibial translation, medial tibial translation and external tibial rotation toward the end of the FSUP exercises is often associated with poor strength[24] or recruitment of the rectus femoris, hamstrings,[16] and hip abductor and adductor muscles.[18] Such strength or recruitment issues should be addressed during rehab or sport preparation.

Regardless, the FSUP exercise is characterized by a greater concentric/eccentric component which occurs due to the additional range of knee extension and hip extension induced by the high bench when compared to the forward lunge performed on the floor.[17] Simenz et al[16] reported that a large knee joint moment is generated together with a quadriceps-hamstring co-contraction in order to help stabilize the knee joint during FSUP exercise. Additionally, the final 45º of knee extension during the step up is often associated with an increase in patellofemoral joint compression, induced by resultant forces produced by quadriceps and patellar tendons.[24] The tibial external rotation and increased strain in the medial collateral ligament may reduce the proprioceptors responses (i.e., muscle spindle and Golgi tendon organ) induced by the ACL strain due to a valgus moment at higher levels of valgus positioning.[9]

There are potentially a multitude of reasons why an individual may demonstrate poor control of loading of the limb during FSUP including: poor proprioception, weakness or poor synchrony control of hip and knee stabilizers muscles (quadriceps, gluteus medius and maximus),[17] and inadequate range of movement at joints such as the ankle[9] resulting in compensatory movement patterns being adopted (i.e., asymmetry). MacAskill et al[17] examined the role of the gluteus medius during dynamic movements such as jump landings and cuts, and reported that strengthening the gluteus medius may reduce the risk of ACL injury through the reduction in dynamic valgus position. Recently, Malloy et al[25] suggested that training the gluteus medius may improve both strength and timing of gluteus medius activation, which may reduce dynamic knee valgus during sport and exercise, reducing risk of ACL injury.

The current study has limitations such the small sample size and the absence of measures such as muscle activation, ground contact time, and jump height during the DVJ and FSUP. However, a thorough understanding of the knee joint biomechanics during jumping and step-up activities is important for understanding presentation of normal athletes, and optimizing rehabilitation protocols so these results may assist many professionals who work with young athletes. Additionally, the findings of the current study regarding the asymmetries noted between dominant and nondominant leg during FSUP, may help conditioning and rehabilitation professionals to value the knee FPPA assessment using low cost and effective 2D kinematic analysis during tasks which exposes lower extremity injury risk.

CONCLUSION

The results of this study have shown a significant difference in FPPA of the nondominant limb when compared to the dominant limb during FSUP task performed by young basketball players. However, these differences were not found during a bilateral landing task the DVJ. These data indicated significant asymmetries between limbs during unilateral task. Therefore, the 2D kinematic analysis of knee joint alignment via FPPA during jumping, landing, lunging, and other unilateral tasks may help conditioning and physical therapists professionals to detect asymmetries between dominant and nondominant limbs, and to develop training programs with the goal of restoring limb symmetry.

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